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# Design and Characterization of 1 by 128 Linear Arrays of Sensitivity Improved InGaAs/InP NIR Photodetector

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## 1. Introduction

InGaAs/InP P-i-N photodetectors are widely used devices in optical communication, biomedical, environmental, agricultural, food, and chemical firms for near-infrared light of 1.0 ㎛ ~ 1.7 ㎛ wavelength. But InGaAs P-i-N photodetectors have structural limitation of low responsivity[1][2]. In low light level, this P-i-N devices couldn't flow enough amount of current which is indispensable to analog signal processing. For more improved optical responsivity, avalanche photodiode(APD) was introduced instead of P-i-N photodetector, but the APD has two major problems, large noise and extremely high bias voltage. InGaAs P-i-N devices still be the most widely used photodetectors for near infrared light detection. We need highly sensitive photodetectors which can flow more amount of current under the same low light intensity.

With this motivation, we present optical sensitivity improved heterojunction phototransistors(HPT) 1 by 128 one dimensional arrays for spectroscopy applications. We also studied the equivalent model of HPT and discuss the relationships between sensitivity and shunt resistance. The proposed HPT has tens of KΩ shunt resistance with moderate optical sensitivity under low illumination, which is enough for effective signal conversion through trans-impedance amplifier circuit.

## 2. Design and Characterization

*Device Equivalent Model*

Electrical equivalent model of HPT is shown in Fig. 1. In a DC mode, photocurrent(Ip) and light dependent shunt resistance(Rsh) are the most important parameters. The series resistance(Rs) of HPT is very low to ignore and the detector capacitance(Cd) doesn't affect device performance in DC mode. Under constant applied bias voltage(Vp) as the incident light power increase the light dependent shunt resistance(Rsh) will be decreased. There exists optical Early effect internal mechanism to maintain Ohm's law. The higher optical sensitivity the lower shunt resistance. Thus, we need some trade off between optical sensitivity and shunt resistance. In case the shunt resistance remains very low under high illumination, the trans-impedance amplifier cannot convert photocurrent to voltage because of input impedance of trans-impedance amplifier. Finally the moderate optical sensitivity and moderate shunt resistance is required for effective conversion without loss of photocurrent. We present HPT structure which has moderate sensitivity and moderate shunt resistance.

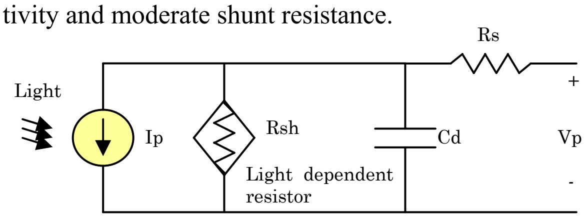


Fig. 1. Equivalent model of HPTs

*Device Structure*

The epitaxial structure of the proposed HPT mainly consists of emitter, base, collector and subcollector layer as was shown in Fig. 2. The device's epi-wafer was grown by MBE on a semi-insulating InP substrate. Carbon was used as the p-type dopant while Si was used as the n-type dopant. The emitter consists of heavily doped 60nm InGaAs($2*10^{19}$)/40nm InP ($2*10^{19}$) cap layer on a 60nm InGaAs($6*10^{17}$) emitter layer to lower emitter contact resistance. Thin undoped InGaAs spacer layer being formed on InGaAs(60nm, $2*10^{19}$) base layer. Beneath the base layer, collector layer was formed by thick InGaAs absorption layer(1200nm, $2*10^{16}$). One very thin InGaAs subcollector was employed as a etch stop to expose the collector contact surface without over etching.

| Layer | Material, Dopant, Doping | Thickness(nm) |
|---|---|---|
| Emitter | InGaAs, Si, $2 * 10^{19}$ | 60 |
| | InP, Si, $2 * 10^{19}$ | 40 |
| | InP, Si, $6 * 10^{17}$ | 60 |
| Spacer | InGaAs, Undoped | 5 |
| Base | InGaAs, C, $2 * 10^{19}$ | 60 |
| Collector | InGaAs, Si, $2 * 10^{16}$ | 1200 |
| Etch-stop | InP, Si, $2 * 10^{19}$ | 10 |
| Subcollector | InGaAs, Si, $2 * 10^{19}$ | 400 |
| Substrate | InP, S.I | |

Fig. 2. Epitaxial Structure of the proposed HPTs

To increase optical gain and responsivity, the HPT's epitaxial layer structure was optimized as the collector doping reduced and the collector thickness increased.[3][4] By placing the absorber in the collector depletion region of an HPT, the photogenerated current is electrically amplified, giving the device gain. Heterojunction phototransistors are particularly attractive as they provide optical gain without the excess noise that characterizes avalanche photodiodes.

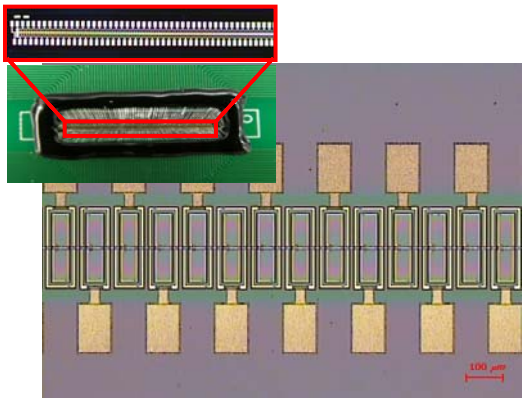

Fig. 3. Microphotograph of the fabricated HPT 1 by 128 array

*Experimental Results*

The HPT one dimensional array, shown in Fig. 3, was fabricated by wet etching the InP with a diluted HCl solution and the InGaAs with a solution of H3PO4, H2O2 and H2O. Non alloyed Ti/Pt/Au was used for all of the device contacts. 1 by 128 InP/InGaAs heterojunction phototransistor arrays with floating base terminal have been fabricated and characterized using frontside optical injection through the top layer. The photocurrent was measured with light incident from a tunable laser source(1550nm wavelength) and using Keithley 4200 semiconductor parameter analyzer. In Fig. 4 we have plotted two terminal HPT's collector current against collector-emitter voltage for different optical powers. The absorption area was 50um * 200um, measured dynamic range was 121dB, average dark current was 38.4nA at 1V bias. Under low illumination, the device exhibited significant optical sensitivity of 46A/W which is higher than that of ever reported HPTs and conventional P-i-N photodiodes with the same light absorbing area.

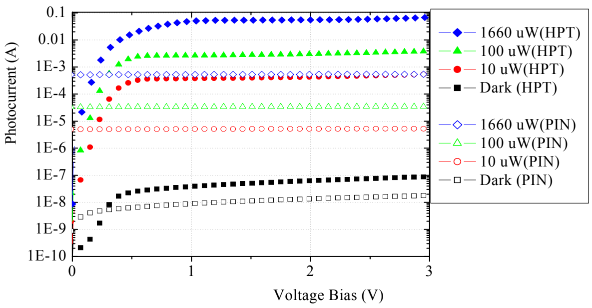


Fig. 4. DC optical properties of HPT and P-i-N photodetector with the same light absorbing area at different incident optical powers

The origin of this high sensitivity is the internal gain enhancement mechanism of the HPT which was previously described. Fig. 5 shows the relationship between the shunt resistance and photocurrent of HPTs. With the results of these devices, we can easily implement highly sensitive Near IR detection systems to recognize very weak optical signals without photocurrent conversion loss.

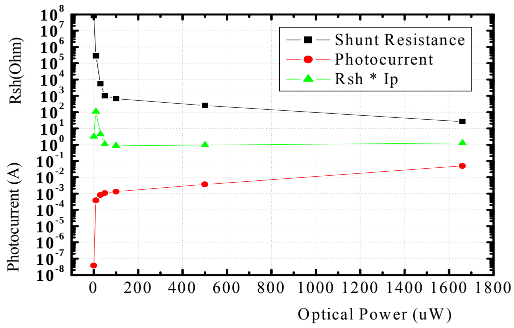


Fig. 5. Relationship between photocurrent level and shunt resistance under different incident power

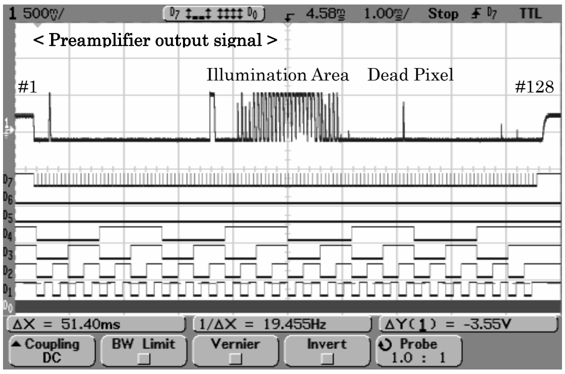


Fig. 6. Preamplifier output waveform(top waveform) and control signals of 1 by 128 detector array under the IR laser illumination

## 3. Conclusions

In this work, we present the structure of optical sensitivity improved InGaAs/InP HPTs and discuss their equivalent model and optical properties. With this device structure, a highly sensitive HPT 1×128 array with two-terminal configurations was fabricated for near-IR spectroscopy applications. The experimental results show an extremely large optical sensitivity of 46 A/W, which is significantly higher than any previously reported HPTs and conventional P-i-N photodetectors with the same light absorbing area. The proposed HPT also has tens of KΩ shunt resistance with moderate optical sensitivity under low illumination, which is enough for effective signal conversion through trans-impedance amplifier circuit.


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